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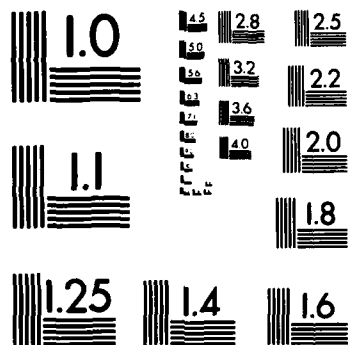
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CHARACTERIZATION OF COMBUSTION PRODUCTS
OF MILITARY PROPELLANTS

FINAL REPORT

Volume II

by

Alan Snelson
Paul Ase
Warren Bock
Ronald Butler

March 1983

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combustion products. Volume I contains the main findings of the theoretical, laboratory, and field studies devoted to the characterization of combustion products of military propellants.

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Simulated propellant combustor. M16 rifle. XM2 Fighting Vehicle, M198 howitzer, and MLRS. Theoretical product distribution calculations.

FOREWORD

IIT Research Institute is pleased to submit this two-volume document as the final report on the "Characterization of Combustion Products from Military Propellants." The study was sponsored by the U.S. Army Medical Bioengineering Research and Development Laboratory under Contract DAMD17-80-C-0019. The program started in February 1980 and the experimental phases ended in October 1982. The report contains much new information on the nature and amounts of combustion products formed in propellant systems not heretofore available.

We would like to acknowledge the enthusiasm and support received from Dr. William Dennis and Captain James W. Carroll of the U.S. Army Medical Bioengineering Research and Development Laboratory during the course of the program. The kind assistance of Dr. Eli Freedman, of the Interior Ballistics Division, Ballistics Research Laboratory, Aberdeen Proving Grounds, in providing theoretical performance calculations on the M6 propellant is also appreciated.

Citation of commercial organizations and trade names in this report does not constitute an official Department of the Army endorsement or approval of the products or services of these organizations.

Respectfully submitted,
IIT RESEARCH INSTITUTE

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APPENDIX I

**SUMMARY OF PROPELLANT COMBUSTION PRODUCT DATA
OBTAINED IN THE LITERATURE SEARCH**

SUMMARY OF PROPELLANT COMBUSTION PRODUCT DATA FROM LITERATURE SEARCH

1. Detonation Calculations (Special Technical Report No. 13)

Department of the Army, Edgewood Arsenal
Contract DA-18-035-AMC-122(A), 1967. AD822301.

This report is largely concerned with the origins of muzzle flash. The propellants listed in Table 1 were considered.

TABLE 1. CALCULATION INPUT PARAMETERS FOR PURE EXPLOSIVES

Chemical Name	Formula	Formula Weight	Oxygen Balance ^a	Crystal Density, g/cc	Heat of Formation	
					kcal/mol	kcal/g
Pentaerythritol tetra-nitrate (PETN)	$C_5H_8N_4O_{12}$	316.2	-10.0	1.77	-125.0	-0.395
Cyclotrimethylene-trinitramine (RDX)	$C_3H_6N_6O_6$	222.1	-22.0	1.80	+14.71	+0.066
Cyclotetramethylene-tetranitramine (HMX)	$C_4H_8N_8O_8$	296.2	-22.0	1.90	+17.93	+0.061
Trinitrotoluene (TNT)	$C_7H_5N_3O_6$	227.1	-74.0	1.64	-17.81	-0.078
Ammonium perchlorate (AP)	NH_4ClO_4	117.5	+34.1 ^b	1.95	-69.42	-0.591
Ammonium nitrate (AN)	NH_4NO_3	80.0	+20.0	1.73	-87.27	-1.091

^a Oxygen balance = $-\frac{1600}{\text{formula wt}} [2 \text{ C atoms} + \frac{H}{2} \text{ atom} - O \text{ atom}]$.

^b Assuming Cl atoms form HCl.

Theoretical product compositions were calculated using two models (LASL and SRI). Typical results are shown in Table 2. In one case the calculated combustion product compositions were compared with some experimental values obtained by the author. No details of the experimental methods were given. The results are shown in Table 3.

TABLE 2. CALCULATED PRODUCT COMPOSITIONS
[Mole%]

Product	HMX, $\rho_o = 1.6$ g/cc		TNT, $\rho_o = 1.6$ g/cc		TNT, $\rho_o = 1.6$ g/cc		RDX, $\rho_o = 1.6$ g/cc	
	LASL	SRI	LASL	SRI	LASL	SRI	LASL	SRI
CO ₂	15.9	17.8	14.3	13.4	11.4	17.1	16.5	18.0
CO	1.5	2.6	2.1	1.3	9.5	7.7	0.2	1.0
CH ₄	--	1.4	--	2.7	--	3.2	--	0.8
C(s)	15.9	14.2	46.7	44.1	42.8	40.2	16.5	14.4
H ₂ O	33.3	30.6	22.7	17.7	22.4	16.6	33.3	31.3
H ₂	--	--	--	--	0.2	0.3	--	--
NH ₃	--	1.2	--	0.7	--	0.7	--	0.9
N ₂	33.3	32.2	13.6	14.1	13.6	14.3	33.3	33.7

TABLE 3. COMPARISON OF CALCULATED AND EXPERIMENTAL EXPANDED
PRODUCT COMPOSITIONS FOR PETN

Product	Experimental		Calculated		Calculated for BKW Isentrope at 1500-1800K
	Confined	Unconfined	for Detonation State		
ρ_o (g/cc)	1.74	1.74	1.77	1.00	1.74
Products (mole/mole PETN)				-	
CO ₂	3.39	3.50	3.95	3.04	4.0-4.1
CO	1.69	1.56	0.096	0.96	0.5-0.6
CH ₄	0.003	<0.0002	<0.0002	0.0002	0.3-0.4
C(s)	None	None	0.951	None	None
H ₂ O	3.50	3.45	4.00	3.94	3.2-3.3
H ₂	0.45	0.51	<0.0002	0.050	0.02-0.05
NH ₃	0.037	<0.0002	<0.0002	0.004	0.04-0.06
N ₂	2.00	2.00	2.00	1.99+	2.0

2. Solid Propellant Combustion Gas Analysis Using a Micrometer Technique

U.S. Air Force, Edwards Air Force Base
Contract AFRPL-TR-69-53, 1969. AD851089.

The combustion products from two composite formulations containing 16% Al, 68% NH_4ClO_4 , and 16% unspecified binder and 15% Al, 30% NH_4ClO_4 , and 55% unspecified binder, were determined experimentally. A small micro-combustor shown in Figure 1 was vented into a large chamber at reduced pressure (250 mm Hg) containing either argon or air. The contained effluents were then analyzed directly by a mass spectrometer within a period of 30 s. Typical results are shown in Tables 4 and 5.

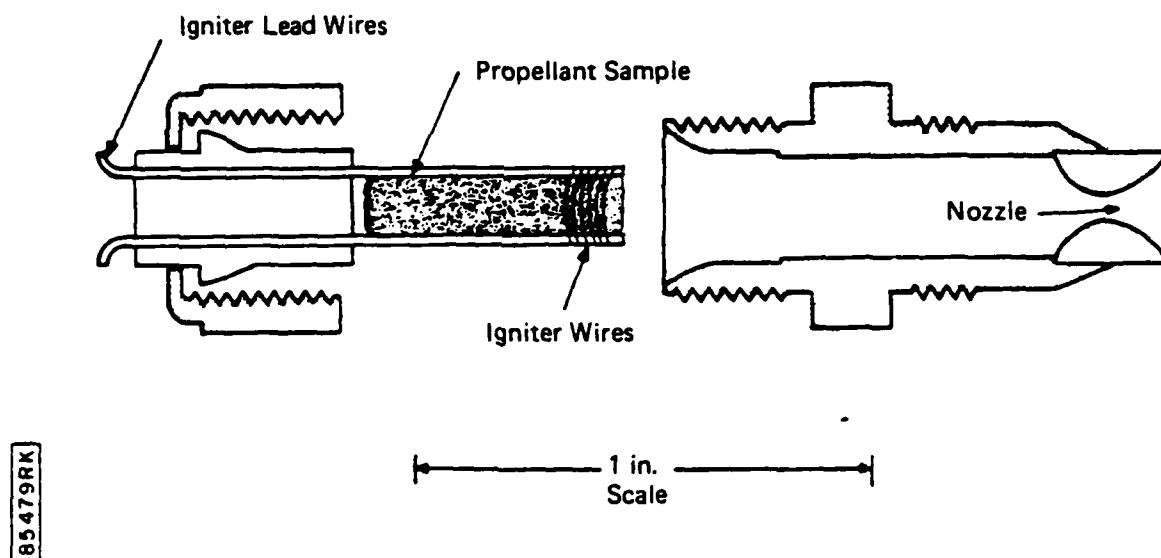


Figure 1. Micromotor design.

TABLE 4. COMPOSITE PROPELLANT FIRED IN ARGON
[Composition in Mole%]

Species	Run No.						Average	Thermo- dynamic Prediction
	10197A	10197B	10207A	10207B	11027A	11027B		
NH ₃	13.7	13.0	19.7	20.0	11.5	11.7	14.7	--
H ₂ O	30.8	22.3	36.9	21.9	12.8	29.6	25.3	19.2
CO	20.1	31.5	15.7	24.2	41.8	20.9	25.3	40.6
N ₂	7.2	11.6	5.7	10.0	14.6	7.0	9.2	12.9
HCl	27.1	20.0	20.9	22.4	15.9	29.2	23.8	24.4
CO ₂	1.1	1.6	1.0	1.4	3.3	1.6	1.7	3.0

**TABLE 5. MODIFIED DOUBLE-BASE PROPELLANT FIRED
IN AIR AND ARGON**
[Composition in Mole%]

Species	Air	Argon	Thermodynamic Prediction
NH ₃	2.7	14.4	--
H ₂ O	28.4	17.9	22.5
CO	9.3	33.8	47.2
N ₂	33.9	17.8	14.3
NO	2.2	3.6	--
HCl	5.2	10.4	10.1
CO ₂	18.4	7.1	5.9

In Figure 2 a graph of the combustion product decay in the holding chamber as a function of time is presented. The decay of the species was attributed to reaction of the gases or adsorption on the walls of the chamber.

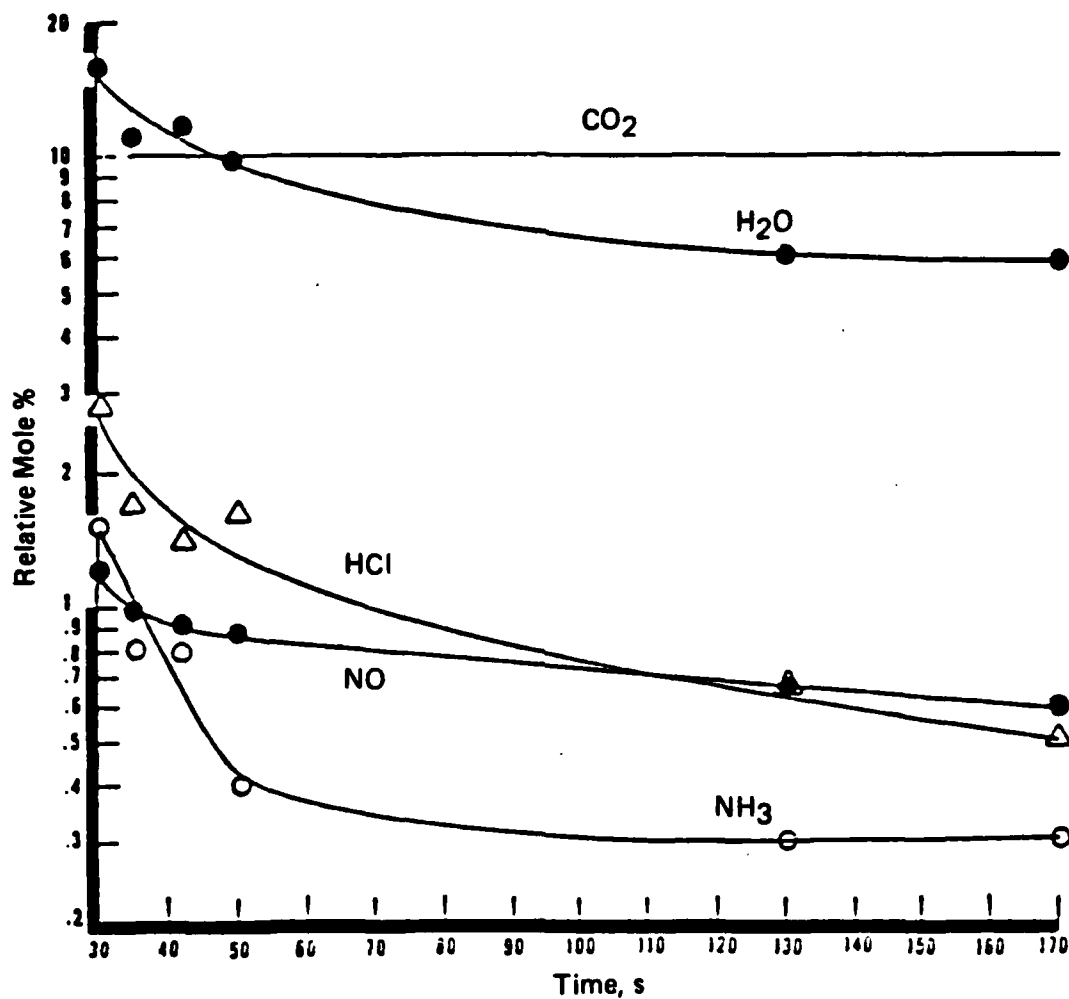


Figure 2. Combustion products decay in air diluent.

3. The Composition of the Exhaust Products of Military Weapons-- A Comparison of Calculated and Experimental Results

Joint USAARL-USAFA Report, USAFA Report R-1968 1970. AD 871485.

The three propellant systems shown in Table 6 were the subject of the investigation described in the project title. An initial literature search, presumably made in the literature prior to 1970, revealed no relevant data on the systems below. Experimental arrangements for sampling gun and rocket propellant system effluents were constructed as indicated in Figures 3 and 4. Chemical analyses were also made by mass spectrometry on the collected species. Aerosols were collected, but it is not clear if they were chemically analyzed.

TABLE 6. PROPELLANT AND WEAPON SYSTEMS

Weapon	7.62mm Machine Gun	Caliber .50 Machine Gun	2.75 in. FFAR
Ammunition	Cartridge, 7.62mm, NATO	Cartridge, Caliber .50,	--
Ball	M80	M33	--
Propellant	WC846	WC860	N-5
Charge Weight	2.92 g	15.99 g	2.68 kg
Component, %			
	WC846	WC860	N-5
Nitrocellulose	82.61 ^a	80.54 ^a	49.7
% Nitrogen	13.12	13.15	12.6
Nitroglycerine	9.86 ^a	8.79 ^a	35.2
Diphenylamine	0.97 ^a	0.94 ^a	--
Dinitrotoluene	0.57 ^a	--	--
Graphite	0.2	0.2	--
Moisture	0.62	1.13	--
Volatiles	0.37	0.37	--
Dibutylphthalate	5.07 ^a	8.11 ^a	--
Diethylphthalate	--	--	10.5
2-Nitrodiphenylamine	--	--	2.0
Wax	--	--	0.2
Sodium sulfate	0.07 ^a	0.12 ^a	--
Calcium carbonate	0.62 ^a	0.49 ^a	--
Potassium nitrate	--	0.73 ^a	--
Lead salicylate	--	--	1.3
Lead 2-ethylhexoate	--	--	1.1

^aReported on a volatile-free basis.

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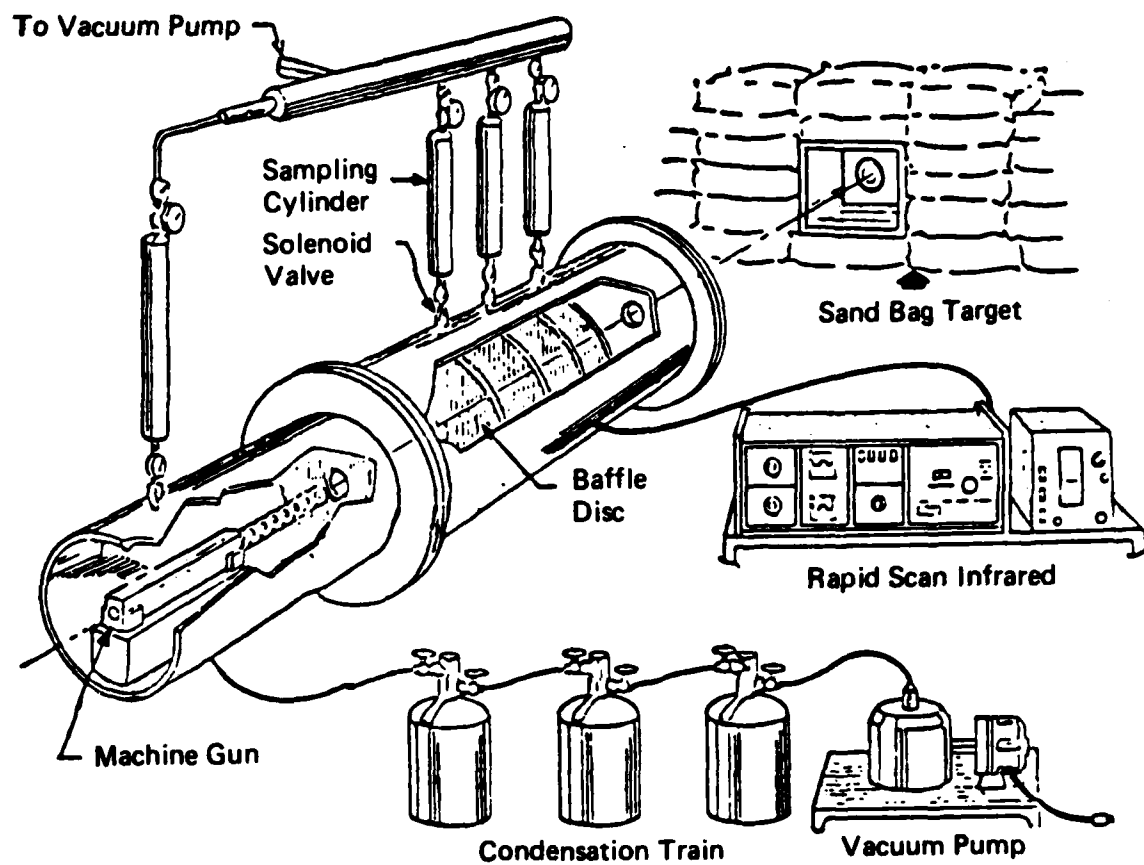


Figure 3. Gun exhaust sampling apparatus and test stand.

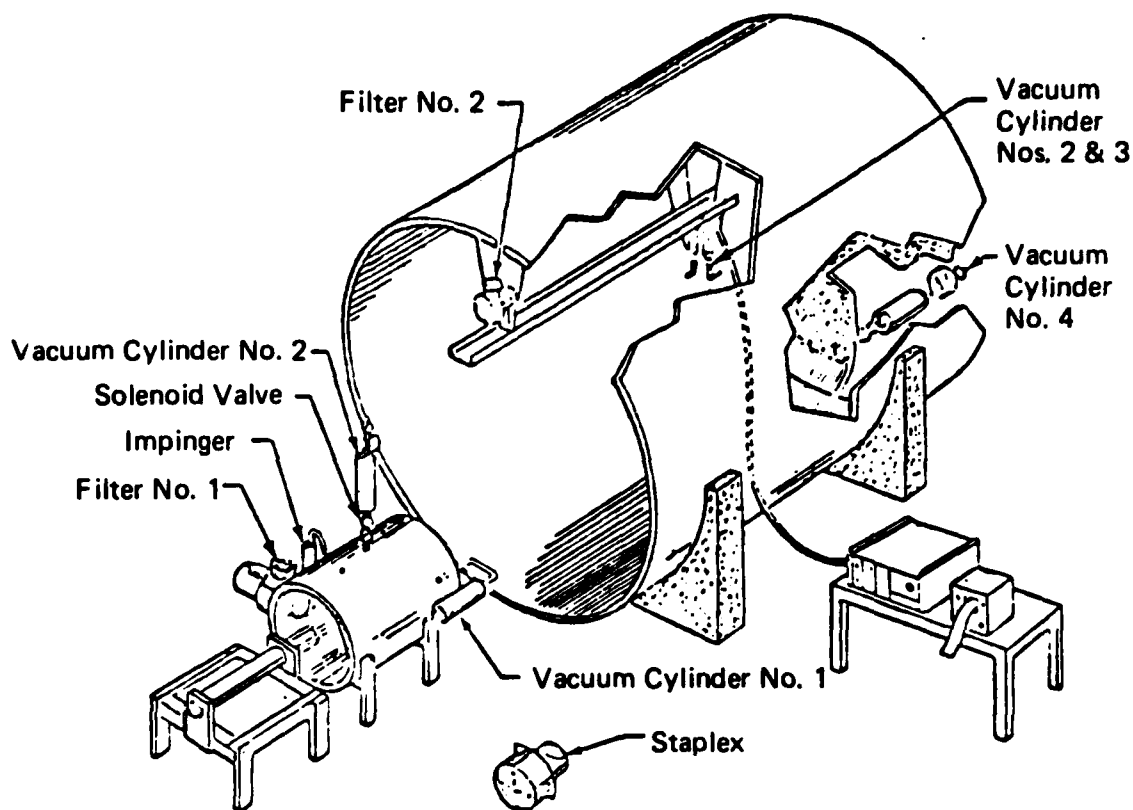


Figure 4. Rocket exhaust sampling apparatus and test stand.

The specific computer program used in the theoretical equilibrium calculations was not identified. The data base was the then existing JANNAF tables. To simplify the calculation, the primer compositions, added stabilizers, or smoke suppressants were not included in the computation.

The results from the study are essentially summarized by the data presented in Tables 7 through 14. In Table 15, the chemical species introduced into the computer computation are presented. It is at once apparent that a number of the species found experimentally, SCO , CH_3CHO , and C_6H_6 were not included in the computer data base.

TABLE 7. COMPARISON OF RECONCILED COMPUTER AND EXPERIMENTAL RESULTS FOR SELECTED EXHAUST COMPONENTS OF THE 2.75 in. ROCKET USING N-5 PROPELLANT
[Mole Fractions]

Component	Calculated Pressure, psi				Experimental	
	1,200	1,000	500	100	14.7	Mean Maximum
CO	0.83E-00	0.83E-00	0.81E-00	0.76E-00	0.65E-00	0.21E-00 0.57E-00
CO ₂	0.16E-00	0.16E-00	0.18E-00	0.23E-00	0.34E-00	0.52E-00 0.70E-00
CH ₄	0.73E-06	0.80E-06	0.13E-05	0.16E-05	0.37E-02	0.60E-02 0.26E-01
NH ₃	0.51E-04	0.31E-04	0.26E-04	0.24E-04	0.41E-04	0.70E-02 0.11E-01
NO ₂	Exponents range from -10 (1200 psi) to -26 (14.7 psi)					None detected
HCN	0.19E-04	0.16E-04	0.94E-05	0.30E-05	0.11E-05	0.30E-02 0.38E-02

TABLE 8. COMPARISON OF RECONCILED COMPUTER AND EXPERIMENTAL RESULTS FOR SELECTED EXHAUST COMPONENTS OF THE 7.62mm MACHINE GUN USING WC846 PROPELLANT
[Mole Fractions]

Component	Calculated Pressure, psi					Experimental	
	50,000	25,000	10,000	5,000	1,000	14.7	Mean Maximum
CO	0.83E-00	0.80E-00	0.78E-00	0.74E-00	0.63E-00	0.28E-00	0.66E-00 0.81E-00
CO ₂	0.18E-00	0.20E-00	0.22E-00	0.25E-00	0.34E-02	0.68E-00	0.26E-00 0.42E-00
CH ₄	0.91E-03	0.14E-02	0.35E-02	0.84E-02	0.39E-01	0.46E-01	0.10E-01 0.15E-01
NH ₃	0.12E-02	0.98E-03	0.83E-03	0.76E-03	0.51E-03	0.11E-03	0.38E-02 0.10E-01
NO ₂	Exponents range from -11 (50,000 psi) to -30 (14.7 psi)						0.20E-02 0.48E-02
HCN	0.65E-03	0.36E-03	0.18E-03	0.10E-03	0.25E-04	0.23E-06	0.55E-03 0.10E-02

TABLE 9. COMPARISON OF RECONCILED COMPUTER AND EXPERIMENTAL RESULTS FOR SELECTED EXHAUST COMPONENTS OF THE CALIBER .50 MACHINE GUN USING WC860 PROPELLANT
[Mole Fractions]

Component	Calculated Pressure, psi						Experimental	
	50,000	25,000	10,000	5,000	1,000	14.7	Mean	Maximum
CO	0.83E-00	0.82E-00	0.78E-00	0.73E-00	0.60E-00	0.26E-00	0.65E-00	0.85E-00
CO ₂	0.15E-00	0.17E-00	0.21E-00	0.24E-00	0.24E-00	0.67E-00	0.27E-00	0.59E-00
CH ₄	0.68E-02	0.11E-01	0.23E-01	0.37E-02	0.67E-01	0.55E-01	0.65E-02	0.93E-02
NH ₃	0.21E-02	0.17E-02	0.13E-02	0.11E-02	0.56E-03	0.12E-03	0.28E-02	0.80E-02
NO ₂	Exponents range from -12 (50000 psi) to -30 (14.7 psi)						0.20E-03	0.50E-03
HCN	0.10E-02	0.55E-03	0.24E-03	0.13E-03	0.25E-04	0.20E-06	0.28E-03	0.88E-03

**TABLE 10. SPECIES PREDICTED BY COMPUTATION BUT NOT DETECTED
BY CHEMICAL EXPERIMENTS^a**

Component ^b	Formula	Typical Mole Fraction Predicted	Pressure Used for Calculation, psi	Propellant
Hydrogen	H ₂	0.26 E-00	14.7	N-5
Carbon, monatomic	C	0.97 E-17	10,000	WC846
Water	H ₂ O	0.94 E-01	14.7	N-5
Nitrogen	N ₂	0.11 E-00	14.7	N-5
Oxygen	O ₂	0.15 E-11	10,000	WC846
Nitric oxide	NO	0.36 E-08	10,000	WC846
Methylidyne	CH	0.19 E-14	10,000	WC846
Methylene	CH ₂	0.81 E-08	10,000	WC846
Methyl	CH ₃	0.19 E-05	10,000	WC846
Imidogen	NH	0.18 E-09	10,000	WC846
Amidogen	NH ₂	0.62 E-07	10,000	WC846
Cyanogen	C ₂ H ₂	0.13 E-09	10,000	WC846
Hydroxyl	OH	0.22 E-06	10,000	WC846

^aSpecific examples of typical results given for illustration.

^bGaseous state.

**TABLE 11. COMPONENTS REPORTED BY CHEMICAL ANALYSIS BUT NOT
PREDICTED IN THE COMPUTATION RESULTS**

Component	Typical Mole Fraction	Weapon
Cyanogen	0.50 E-03	All
Carbonyl sulfide	0.10 E-03	Both machine guns
Benzene	0.10 E-04	7.62 mm machine gun
Acetaldehyde	0.50 E-03	Caliber .50 machine gun
Hydrogen chloride	Trace	Rocket plume only
Sulfur dioxide	Trace	Rocket plume only
Copper and lead	50 mg/m ³ of air	Both machine guns

TABLE 12. PROJECT WEST DATA, CALIBER .50 MACHINE GUN

Run	LOC Inst Code	Sample Press.	CO Partial Press.	CO ₂		CH ₄		NH ₃		NO ₂		HCN		C≡N		CH ₃ CHO		SCO		C ₆ H ₆		C ₂ H ₂	
				P	R	P	R	P	R	P	R	P	R	P	R	P	R	P	R	P	R	P	R
2	MUZ1 IR	68	45	18	400	0.6	13	0.15	3	--	--	--	--	--	--	--	--	--	--	--	--	--	--
3	MUZ1 IR	71	45	20	430	0.5	10	0.30	7	--	--	--	--	--	--	--	--	--	--	--	--	--	--
4	MUZ1 IR	93	32	55	1700	0.5	14	0.15	5	--	--	--	--	--	--	--	--	--	--	--	--	--	--
5	MUZ1 IR	180	14	170	12000	--	--	--	--	0.09	7	--	--	--	--	--	--	--	--	--	--	--	--
	MUZ 102	--	~10	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
6	MUZ 102	--	~80	--	--	--	--	--	~1	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	MUZ5 IR	140	98	36	370	1.1	11	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	MUZ1 M	160	120	24	200	1.2	10	0.41	4	--	--	0.14	1	0.01	0.1	--	--	--	--	--	--	0.7	0.6
7	MUZ1 IR	150	99	38	380	1.4	14	0.45	5	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	MUZ3 IR	180	130	48	380	1.5	12	0.75	6	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	MUZ5 IR	120	83	32	380	1.1	13	0.36	4	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	MUZ3 M	240	160	45	290	0.7	5	0.41	4	--	--	0.04	0.3	0.08	0.5	1.5	10	0.03	0.1	--	--	0.07	0.4
8	MUZ1 IR	92	65	23	360	0.8	12	0.51	8	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	MUZ3 IR	150	110	40	380	1.3	12	0.90	9	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	MUZ5 IR	100	73	26	350	0.8	10	0.80	10	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	MUZ 102	--	~200	--	--	--	--	~2	~10	--	--	--	--	--	--	--	--	--	--	--	--	--	--
9	MUZ3 M	45	38	6	170	0.2	6	0.03	0.8	--	--	0.1	0.4	--	--	0.01	0.4	--	--	--	--	0.02	0.6
	MUZ 102	--	300	--	--	--	~2	~7	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
10	RCV IR	15	6	1000	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	MUZ3 M	270	210	60	280	2.5	12	0.2	1	--	--	0.01	0.05	0.03	0.2	0.14	0.5	0.02	0.1	--	--	0.14	0.5
11	RCV IR	19	8	5	690	0.09	12	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	MUZ3 M	110	88	20	230	0.14	2	0.02	0.2	--	--	0.007	0.07	0.003	0.04	0.007	0.04	--	--	--	--	0.0	0.2
	RCV 102	--	~10	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
12	RCV IR	26	14	9	640	0.09	7	0.03	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	MUZ3 M	80	62	18	280	0.34	5	0.03	0.5	--	--	0.03	0.5	0.01	0.2	0.03	0.5	0.007	0.1	--	--	0.04	0.7
14	RCV IR	28	14	11	790	0.03	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

TABLE 13. PROJECT WEST DATA, 7.62mm MACHINE GUN

Run	LOC Code	Inst Code	Total Sample Press.	CO Partial Press.	CO ₂		CH ₄		NH ₃		NO ₂		HCN		C≡N		CH ₃ CHO		SCO		C ₆ H ₆		C ₂ H ₂	
					P	R	P	R	P	R	P	R	P	R	P	R	P	R	P	R	P	R	P	R
15	MUZ1	IR	25	5.4	18	3300	--	--	--	--	0.12	22	--	--	--	--	--	--	--	--	--	--	--	--
	MUZ3	IR	27	3.6	22	6100	0.3	8	--	--	0.09	25	--	--	--	--	--	--	--	--	--	--	--	--
	MUZ5	IR	19	5.7	13	2300	0.03	5	--	--	0.06	11	--	--	--	--	--	--	--	--	--	--	--	--
	RCV	IR	8.4	1.8	4	2000	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
16	MUZ1	IR	6	4.5	2	330	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	MUZ5	IR	9.6	5.7	4	680	0.06	11	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	RCV	IR	49	30	12	400	0.66	22	0.33	11	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	MUZ3	49	34	7	220	0.48	15	0.07	2	--	--	0.052	0.01	0.3	0.06	2	0.002	--	0.04	0.001	0.02	0.05	2	--
17	MUZ1	IR	170	96	52	540	2.3	23	0.15	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	RCV	IR	44	21	13	610	0.4	19	0.27	13	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	MUZ3	M	170	130	33	270	1.4	12	0.07	0.6	--	--	0.03	0.3	0.03	0.3	--	0.003	0.03	0.002	0.02	0.05	0.4	--
	MUZ	102	--	~200	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
18	MUZ1	IR	180	120	42	360	2.1	16	0.48	4	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	RCV	IR	66	36	17	460	0.8	21	0.51	14	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	MUZ	102	--	~100	--	--	--	--	1	10	--	--	--	--	--	--	--	--	--	--	--	--	--	--
19	MUZ5	IR	130	90	30	330	1.5	17	0.33	4	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	RCV	IR	75	45	20	430	0.8	17	0.45	10	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	RCV	IR	92	52	24	460	0.8	16	0.70	13	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	RCV	102	--	~30	--	--	--	--	1	33	--	--	--	--	--	--	--	--	--	--	--	--	--	--
20	MUZ1	IR	170	110	40	350	2.2	20	0.33	3	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	MUZ5	IR	110	80	26	330	1.6	20	0.12	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	RCV	IR	56	34	15	430	0.8	22	0.57	17	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	RCV	IR	31	20	8	410	0.4	19	0.27	13	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	MUZ5	M	140	110	29	260	1.3	11	0.20	2	--	--	0.07	0.7	0.14	1.4	--	0.03	0.3	--	--	0.07	0.7	--
	RCV	M	--	63	18	290	1.1	17	0.14	2	--	--	0.07	1.2	0.14	2.0	--	0.05	0.8	--	--	0.07	1.3	--
	RCV	102	--	~30	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
21	MUZ1	IR	300	200	75	360	1.9	9	0.30	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	MUZ5	IR	130	84	36	430	0.9	11	0.18	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	RCV	IR	24	13	8	580	0.12	9	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	RCV	IR	20	13	8	600	0.09	7	~0.01	~2	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	MUZ3	M	210	170	35	220	1.4	9	0.14	0.08	--	--	0.11	0.7	0.03	0.20	--	--	--	--	--	--	--	--
	RCV	M	35	27	8	270	0.5	19	0.27	11	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	RCV	102	--	~20	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

TABLE 14. PROJECT WEST DATA, 2.75 in. ROCKET (FFAR)

Run	LOC Code	Inst Code	Total Sample Press.	CO Partial Press.	CO ₂		CH ₄		NH ₃		NO ₂		HCN		C≡N		CH ₃ CHO		SCO		C ₆ H ₆		C ₂ H ₂	
					P	R	P	R	P	R	P	R	P	R	P	R	P	R	P	R	P	R	P	R
25	TANK	IR	15	2.4	10	4300	0.03	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	TANK	IR	13	1.1	6	5900	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	TANK	IR	20	1.5	12	7900	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
26	TANK	IR	43	4.0	29	7400	0.04	10	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	TANK	IR	56	7.0	39	5600	0.93	135	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
27	TANK	IR	18	5.3	8	1400	0.08	15	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	TANK	IR	23	5.1	11	2200	0.09	18	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	TANK	IR	40	8.4	22	2700	0.03	3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	PROBE	M	32	16	14	880	0.07	6	--	--	--	0.03	2	--	--	--	--	--	--	--	-0.03	--	2	--
	TANK	102	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
28	TANK	IR	21	4	13	3200	0.07	17	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	TANK	IR	20	3.9	11	3300	0.06	17	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	TANK	IR	49	7.2	31	4300	0.11	15	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	PROBE	M	61	27	31	1200	0.54	20	0.007	2	--	0.11	4	0.07	3	--	--	--	--	--	--	0.14	5	--
29	TANK	IR	34	7.3	17	2300	0.15	20	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	TANK	IR	40	7.0	23	3400	0.09	13	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	PROBE	IR	59	20	29	1500	0.33	17	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	TANK	M	37	15	14	930	0.65	42	0.41	25	--	0.14	10	--	--	--	--	--	--	--	--	0.14	10	--
	TANK	102	--	~6	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
30	TANK	IR	28	9.3	12	1300	0.15	16	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	TANK	IR	41	10	21	2100	0.15	15	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	PROBE	IR	29	14	10	730	0.19	13	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	TANK	IR	43	17	16	930	0.17	10	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	TANK	102	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
31	TANK	IR	29	9.7	13	1400	0.15	15	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	TANK	IR	37	11	19	1700	0.13	12	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	PROBE	IR	120	55	51	930	0.47	9	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	TANK	IR	50	13	27	2200	0.15	12	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	TANK	102	--	~6	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	TANK	M	91	52	24	450	2.4	47	0.27	5	--	0.20	3	0.06	1	--	--	--	--	--	--	--	--	--

TABLE 15. CHEMICAL SPECIES USED IN THEORETICAL PERFORMANCE CALCULATIONS

Formula	Species	Formula	Species
C	Carbon, monatomic	H ₂	Hydrogen, diatomic (reference state, gaseous)
C ₂	Carbon, diatomic	H ₂ O	Water
C ₃	Carbon, trimeric	HCN	Hydrogen cyanide
CH	Methylidyne	N	Nitrogen, diatomic
CH ₂	Methylene	N ₂	Nitrogen, diatomic
CH ₃	Methyl	NH	Imidogen
CH ₄	Methane	NH ₂	Amidogen
C ₂ H ₂	Acetylene	NH ₃	Ammonia
C ₂ N ₂	Cyanogen	NO	Nitric oxide
CO	Carbon monoxide	NO ₂	Nitrogen dioxide
CO ₂	Carbon dioxide	O	Oxygen, monatomic
C(S)	Carbon (reference state, graphite)	O ₂	Oxygen, diatomic
H	Hydrogen, monatomic	OH	Hydroxyl

4. Analysis of Exhaust Gases from the XM-19 Rifle--An Application of Gas Chromatography/Mass Spectrometry

USA Ballistic Research Laboratories, Aberdeen Proving Grounds
ROT E Project No. IJ563607D013, 1973. AD 910937.

The above chemical analytical technique was used to determine the composition of gases resulting from firing the XM-19 rifle with the XM-645 flechette round and the results compared with theoretical performance calculations. The experimental sampling arrangement was similar to that used in the previous study with the rifle mounted in a suitable stand. Gas samples were withdrawn from the enclosure area, after firing a number of rounds, in evacuated glass flasks. In addition, some cryogenic trapping procedures were also used. No attempt to collect aerosol samples was made.

Theoretical product calculations were made with a code named Blake--a modification of the Tiger code developed by SRI for BRL. The modifications were made by Dr. E. Freedman of BRL. The chemical species included in the calculation are given in Table 16 and the propellant composition in Table 17. Typical results from the program are presented in Table 18.

TABLE 16. LIST OF CHEMICAL SPECIES
INCLUDED IN THERMODYNAMIC
CALCULATIONS^a

CO	S
H ₂ O	O ₂
H ₂	C ₂ H ₂
N ₂	C ₂ H ₄
CO ₂	CNCN
KOH	OH
H ₂ S	CN
NH ₃	HS
HCN	SO
K	CH ₃
CH ₂ O	H
COS	KO
NO	O
SO ₂	N
CH ₄	C

^aAll species in gaseous state,
except C, a solid.

**TABLE 17. NOMINAL COMPOSITION OF X-2374.13 PROPELLANT
AND PISTON PRIMER**

Propellant	Weight	Component	Wt%	% of Total Weight ^a
X-2374.13	1.3 g	Nitrocellulose	85.0	82.6
		Nitroglycerine	9.4	9.1
		Diphenylamine	0.9	.88
		Dinitrotoluene	0.7	.68
		Dibutyl phthalate	2.8	2.7
		Potassium sulfate	0.5	.48
		Moisture and volatiles	0.7	.68
Piston Primer	0.037 g	Lead styphnate	37 ±5	1.02
		Tetracene	4 ±1	.11
		Barium nitrate	32 ±5	.89
		Antimony sulfide	15 ±2	.41
		Aluminum powder	7 ±1	.19
		PETN	5 ±1	.14
Total^b	1.337 g			100%

^aPercent component weight of total charge; propellant and primer.

^bTotal weight of propellant and primer.

TABLE 18. COMPARISON OF EXPERIMENTAL AND CALCULATED PRODUCT CONCENTRATIONS FOR X-2374.13 PROPELLANT^a

Species	Calculated	Measured	Species	Calculated	Measured
CO	1000	(1000)	C ₂ H ₂	2.86x10 ⁻⁵	>1 ^b
H ₂ O	476	dnm ^c	C ₂ H ₄	3.80x10 ⁻⁵	
H ₂	389		CNCN	1.57x10 ⁻⁸	.25
N ₂	289	dnm	OH	5.97x10 ⁻⁴	
CO ₂	364	380	CN	1.45x10 ⁻⁸	
KOH	3.34		HS	3.73x10 ⁻³	
H ₂ S	1.65		SO	8.27x10 ⁻⁵	
NH ₃	3.66x10 ⁻¹	dnm	CH ₃	2.28x10 ⁻⁴	
HCN	3.69x10 ⁻²	dnm	H	1.01x10 ⁻²	
K	1.97x10 ⁻¹		KO	8.43x10 ⁻⁷	
CH ₂ O	1.98x10 ⁻²		O	1.28x10 ⁻⁸	
COS	1.18x10 ⁻¹	.25	N	3.10x10 ⁻¹⁰	
NO	1.08x10 ⁻⁵	dnm	C ₃ H ₄	(NI) ^d	<.1
SO ₂	3.35x10 ⁻⁴		C ₃ H ₆	(NI)	.1
CH ₄	3.56x10 ⁻¹	1	C ₃ H ₈	(NI)	<.1
S	8.29x10 ⁻⁶		C ₂ H ₆	(NI)	dnm
O ₂	7.27x10 ⁻⁹	dnm			

^aValues are normalized to CO; [(Concentration of component/concentration of CO) x 10³]

^bMeasured value includes both C₂H₂ and C₂H₄.

^cDetected, but did not quantify

^dNot included in these calculations.

5. Reduced-Smoke Solid Propellant Combustion Products Analysis--
Development of a Micromotor Combustor Technique

U.S. Air Force, Edwards Air Force Base
Job Order No. 573010CN, 1976. AD A032152.

A small motor was developed to burn a few grams of the rocket propellant given in Table 19 at pressures from 200-1500 psi with subsequent analysis of nine condensable gases by gas chromatography and mass spectrometry. For the former technique, gas samples of the combustion effluents were collected in evacuated glass flasks or metal cylinders. In the latter technique, a water-cooled probe was used to sample directly into the mass spectrometer from the motor exit nozzle. Typical analytical data are shown in Tables 20 and 21 where the results of theoretical calculations are also given for comparison. No details of the theoretical computations were given.

TABLE 19. ROCKET PROPELLANT COMPOSITION

Ingredient	Wt%
Binder	12.5
Ammonium perchlorate	85.0
Zirconium carbide	0.5
Graphite	1.0
Aluminum oxide	0.5
Ferric fluoride	0.5

TABLE 20. COMBINED ANALYTICAL DATA
[Reduced-Smoke Propellant, Combustion Gas Composition]

Species	Mass Spectral Mean	Gas Chromatographic Mean	Combined Mean	Theoretical Data
H ₂	20.1	20.1	20.1	16.1
N ₂	53.4	21.6	21.6	23.2
CO		31.2	31.2	33.2
CO ₂	26.0	26.9	26.5	27.6
CH ₄	0.19	0.13	0.16	--
C ₂ H ₂	0.15	0.06	0.11	--
O ₂	0.23	--	0.23	0.21
<u>Ratio</u>				
CO/CO ₂			1.177	1.202
N ₂ /CO ₂			0.815	0.841
H ₂ /CO ₂			0.758	0.583

TABLE 21. HIGH PRESSURE COMBUSTION GAS CORRELATION

Species	High, 1500 psi	Average, 350-1000 psi	Theoretical, 500-1500 psi
H ₂	22.0	20.1	16.1
N ₂	20.3	21.6	23.2
CO	33.1	31.2	33.2
CO ₂	24.2	26.5	27.6
CH ₄	0.16	0.16	--
C ₂ H ₂	--	0.11	--
O ₂	0.14	0.23	0.21
<u>Ratio</u>			
CO/CO ₂	1.37	1.18	1.20
N ₂ /CO ₂	0.84	0.82	0.84
H ₂ /CO ₂	0.91	0.76	0.58

6. Summary of Airborne Chlorine and Hydrogen Chloride Gas Measurements for August 10 and September 6, 1977, Voyager Launches at Air Force Eastern Test Range, Florida

NASA Technical Memorandum 78673, 1978.

This program presents the results of an airborne sampling program in the wakes of Titan rockets. Measurements were made from about 2 min after launch to as long as 4-1/2 h after launch. All sampling was at an altitude of 500-1500 m at distances out to 100 km from the launch pad. Maximum observed hydrogen chloride concentrations for both launches was ≈ 25 -30 ppm occurring 2-6 min after launch. Maxima in the chlorine concentration at 40-55 ppb occurred in the same time frame. Details of the analytical techniques were given. In addition, the exhaust product composition from a Titan rocket was given. This is shown in Table 22.

TABLE 22. EXHAUST PRODUCT COMPOSITION

Species	Formula	Mass Fraction Afterburned Plume ^a	Nominal Conc. in Stabilized Ground Cloud ^b
Aluminum oxide	Al ₂ O ₃	30.4	1000-3000 $\mu\text{g}/\text{m}^3$
Carbon monoxide	CO	.1	<1 ppm
Hydrogen chloride	HCl	20.4	5-40 ppm
Water vapor	H ₂ O	31.9	-- ^c
Carbon dioxide	CO ₂	48.0	Ambient Values
Chlorine	Cl ₂	2.3	-- ^d
Nitrogen oxide	NO	1.2	200-800 ppb
Others	--	0.6	-- ^c

^aIncludes only that entrained air combusted in afterburning; total mass fraction is greater than 100% as reference mass for calculation is exhaust effluents from the motors.

^bRange of nominal concentrations measured in earlier Titan III monitoring programs (Refs. 2-6 of NASA TM-78673).

^cNot measured in monitoring program.

^dNot measured in previous monitoring program.

7. Toxicological and Recalcitrant Properties of a Proposed Propellant Ingredient, Triaminoguanidine Nitrate (TAGN) Analysis of the Deflagration By-Products of a TAGN-Based Propellant

U.S. Air Force, Eglin Air Force Base, Florida
Report No. AFATL-TR-76-161, 1976. AD A041050.

The propellant formulations listed in Table 23 were subject to combustion in closed bombs at terminal pressures in the range of 11,500 to 31,000 psi, and the combustion products were analyzed by gas chromatography. The results are presented in Table 24.

**TABLE 23. FORMULATIONS OF THE VARIOUS PROPELLANTS
USED IN THIS STUDY**

Propellant	Chemical Composition	% Total*
Hercules' GAU-8 Extract	Nitrocellulose (NC)	82.30
	Nitroglycerine (NG)	9.37
	Dibutyl phthalate (DBP)	4.17
	Diphenylamine (DPA)	0.54
	Potassium nitrate (KNO ₃)	0.56
	Hercote C _{5.142} H _{8.75} O _{1.838}	3.06
Rocketdyne's RGP-150	Nitrocellulose (NC)	19.00
	Triaminoguanidine nitrate (TAGN)	45.00
	Cyclotetramethylenetetranitramine (HMX)	30.00
	Isodecyl pelargonate (IDP)	5.00
	Resorcinol	1.00
M-10	Nitrocellulose (NC)	97.40
	Diphenylamine (DPA)	1.00
	Graphite glaze	0.10
	Carbon black	0.50
	Potassium sulfate (K ₂ SO ₄)	1.00
Triple Base	Nitrocellulose (NC)	28.04
	Nitroglycerine (NG)	20.12
	Ethylcellulose (EC)	1.00
	Potassium sulfate (K ₂ SO ₄)	0.25
	Nitroguanidine (NQ)	50.59
WC870	Nitrocellulose (NC)	80.23
	Nitroglycerine (NG)	9.66
	Diphenylamine (DPA)	1.06
	Potassium nitrate (KNO ₃)	0.50
	Dibutylphthalate (DBP)	7.38
	Potassium sulfate (K ₂ SO ₄)	0.38
	Dinitrotoluene (DNT)	0.52
	Calcium carbonate (CaCO ₃)	0.05
	Sodium sulfate (Na ₂ SO ₄)	0.12
	Graphite	0.10

*Among product batches, it is common to have minor variations in constituent percentages.

TABLE 24. PERCENTAGES OF GASES PRODUCED WHEN SELECTED PROPELLANTS WERE BURNED UNDER HIGH AND LOW PRESSURES

Propellant	Pressure, psi	H ₂	N ₂	O ₂	N ₂ O	CO	CO ₂	CH ₄	C ₂ H ₄	H ₂ O
RGP-150	Atm	--	84.0	8.7	--	--	5.8	--	--	1.5
RGP-150	13,000	0.2	42.2	tr	--	40.0	6.4	4.6	--	6.6
RGP-150	31,000	0.3	41.3	0.1	--	31.4	10.0	12.7	--	4.2
GAU-8 Extract	Atm	--	43.5	7.4	--	5.8	28.9	tr	--	14.4
GAU-8 Extract	11,500	0.3	15.3	0.3	--	50.9	14.8	2.3	--	16.1
GAU-8 Extract	28,000	0.3	12.7	--	--	42.0	20.8	7.1	--	17.1
M-10	Atm	--	51.0	15.7	--	1.6	22.2	--	--	9.5
M-10	13,000	0.4	16.2	--	--	57.7	20.4	1.3	--	4.0
M-10	30,000	0.2	15.6	--	--	40.9	30.2	3.2	--	9.9
WC870	Atm	--	60.6	5.1	--	4.0	20.2	--	--	10.1
WC870	12,000	0.3	16.2	--	--	60.6	16.3	2.4	--	4.2
WC870	27,000	0.2	16.6	0.3	--	49.0	25.4	4.9	--	3.6
Triple Base	Atm	--	62.9	17.5	tr	5.5	4.1	--	2.6	7.4
Triple Base	13,000	tr	37.8	--	--	38.7	12.5	2.0	--	9.0
Triple Base	27,000	tr	35.9	--	--	38.9	14.2	2.1	--	8.9

APPENDIX II

THEORETICAL COMBUSTION PRODUCT CALCULATIONS FOR THE WC844 PROPELLANT
ASSUMING EQUILIBRIUM AND FROZEN COMPOSITIONS DURING EXPANSION
AT INITIAL PRODUCT PRESSURES OF 20,000, 30,000,
40,000, 50,000, AND 60,000 psi

TABLE 25. THEORETICAL ROCKET PERFORMANCE ASSUMING EQUILIBRIUM COMPOSITION DURING EXPANSION (page 1 of 2)
[10,000 psi]

PC = 10000.0 PSIA									
CHEMICAL FORMULA									
FUEL	C	6.00000	H	7.36400	N	2.63580	O	10.27200	
FUEL	C	1.00000							
FUEL	C	12.00000	H	11.00000	N	1.00000			
FUEL	C	18.00000	H	14.00000	O	4.00000			
FUEL	NA	2.00000	S	1.00000	O	4.00000			
FUEL	CA	1.00000	C	1.00000	O	3.00000			
O/F= 0.0 PERCENT FUEL= 100.0000 EQUIVALENCE RATIO= 1.6846 PHI= 0.0 REACTANT DENSITY= 0.0									
WT FRACTION (SEE NOTE) ENERGY CAL/MOL STATE TEMP DEG K DENSITY G/CC									
		0.951500				-164700.000	S	298.15	0.0
		0.004000				0.0	S	298.15	0.0
		0.007500				27900.000	S	298.15	0.0
		0.030000				-200000.000	S	298.15	0.0
		0.005000				-326300.000	S	298.15	0.0
		0.002000				-287900.000	S	298.15	0.0
CHAMBER THROAT									
PC/P	1.0000	1.7966	1.0021	1.0087	1.3420	33.855	EXIT	EXIT	EXIT
P, ATM	680.46	378.74	679.03	674.58	507.06	20.099	84.726	198.73	586.57
T, DEG K	2376.2	2122.6	2375.2	2372.2	2245.8	1218.2	1071.1	990.2	917.6
RHO, G/CC	8.5083-2	5.3017-2	8.4940-2	8.4489-2	7.7420-2	6.7084-2	4.9387-3	2.2834-3	1.0794-3
M, CAL/G	-594.6	-701.9	-595.0	-596.3	-616.9	-650.0	-1089.3	-1173.2	-1242.0
S, CAL/(G)(K)	2.1593	2.1593	2.1593	2.1593	2.1593	2.1593	2.1593	2.1593	2.1593
M, MOL WT (DLV/DLP)T									
	24.380	24.381	24.380	24.380	24.381	24.562	24.989	25.614	26.461
(DLV/DLP)T	-1.00046	-1.00037	-1.00046	-1.00046	-1.00040	-1.01060	-1.03436	-1.09871	-1.08867
(DLV/DLP)P	1.0031	1.0022	1.0031	1.0031	1.0025	1.1333	1.4968	2.7932	2.7198
CP, CAL/(G)(K)	0.4285	0.4209	0.4284	0.4283	0.4266	0.4241	0.5559	0.9989	2.9946
GAMMA (SI)	1.2360	1.2409	1.2360	1.2361	1.2372	1.2388	1.2141	1.1682	1.1153
SON VEL, M/SEC	1000.8	947.7	1000.6	1000.0	990.2	974.0	645.2	598.7	565.3
MACH NUMBER	0.0	1.000	0.059	0.119	0.437	0.699	2.876	3.410	4.361
AE/AT									
	1.0000	1.0000	1.0000	1.0000	1.5000	1.1000	5.0000	10.000	50.000
CSTAR, FT/SEC	4502	4502	4502	4502	4502	4502	4502	4502	4502
CF	0.691	0.043	0.087	0.315	0.496	1.483	1.604	1.696	1.796
IVAC LB-SEC/LB	174.5	1402.3	705.7	230.9	184.1	228.1	240.9	251.4	263.3
Isp, LB-SFC/LB	96.6	6.0	12.1	44.1	69.4	207.5	224.4	237.3	251.4

TABLE 27. THEORETICAL ROCKET PERFORMANCE ASSUMING EQUILIBRIUM COMPOSITION DURING EXPANSION (page 1 of 2)
[30,000 psi]

PC = 30000.0 PSIA

CHEMICAL FORMULA										WT FRACTION (SEE NOTE)				ENERGY CAL/MOL		STATE		TEMP DEG K		DENSITY G/CC	
FUEL	C	6.00000	H	7.36400	N	2.63580	O	10.27200		0.951500				-164700.000		S		298.15		0.0	
FUEL	C	1.00000								0.004000				0.0		S		298.15		0.0	
FUEL	C	12.00000	H	11.00000	N	1.00000				0.007500				27900.000		S		298.15		0.0	
FUEL	C	18.00000	H	14.00000	O	4.00000				0.030000				-200000.000		S		298.15		0.0	
FUEL	NA	2.00000	S	1.00000	O	4.00000				0.005000				-326300.000		S		298.15		0.0	
FUEL	CA	1.00000	C	1.00000	O	3.00000				0.002000				-287900.000		S		298.15		0.0	
O/F= 0.0										PERCENT FUEL= 100.0000				EQUIVALENCE RATIO= 1.6846		PHI= 0.0		REACTANT DENSITY= 0.0			
PC/P	CHAMBER	THROAT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	
P, ATM	1.0000	1.7964	1.0021	1.0087	1.1239	1.3419	1.5212	1.6153	1.6153	1.6153	1.6153	1.6153	1.6153	1.6153	1.6153	1.6153	1.6153	1.6153	1.6153	1.6153	
T, DEG K	2041.37	1136.36	2037.08	2023.72	1816.39	1521.24	1247.7	1043.6	962.1	880.8	809.5	748.1	696.5	653.8	618.8	590.0	566.5	547.5	532.0	508.0	
RHD, G/CC	2.5525	1.5906	2.5482	2.5346	2.3225	2.0125	1.6824	1.4824	1.3218	1.1740	1.0448	0.9335	0.8452	0.7750	0.7181	0.6713	0.6333	0.6020	0.5765	0.5530	
H, CAL/G	-594.6	-701.9	-595.0	-596.3	-616.9	-650.0	-688.8	-724.0	-756.5	-786.0	-812.8	-837.0	-858.8	-877.0	-892.0	-904.0	-914.0	-922.0	-933.0	-937.0	
S, CAL/(G)(K)	2.0698	2.0698	2.0698	2.0698	2.0698	2.0698	2.0698	2.0698	2.0698	2.0698	2.0698	2.0698	2.0698	2.0698	2.0698	2.0698	2.0698	2.0698	2.0698	2.0698	
M, MOL WT	24.401	24.400	24.400	24.401	24.400	24.400	24.400	24.400	24.400	24.400	24.400	24.400	24.400	24.400	24.400	24.400	24.400	24.400	24.400	24.400	
(DLV/DLP)T	-1.00132	-1.00133	-1.00132	-1.00132	-1.00130	-1.00129	-1.00129	-1.00129	-1.00129	-1.00129	-1.00129	-1.00129	-1.00129	-1.00129	-1.00129	-1.00129	-1.00129	-1.00129	-1.00129	-1.00129	
(DLV/DLP)P	1.0062	1.0075	1.0062	1.0062	1.0063	1.0066	1.0066	1.0066	1.0066	1.0066	1.0066	1.0066	1.0066	1.0066	1.0066	1.0066	1.0066	1.0066	1.0066	1.0066	
CP, CAL/(G)(K)	0.4289	0.4274	0.4288	0.4287	0.4273	0.4255	0.4255	0.4255	0.4255	0.4255	0.4255	0.4255	0.4255	0.4255	0.4255	0.4255	0.4255	0.4255	0.4255	0.4255	
GAMMA (S)	1.2360	1.2406	1.2360	1.2361	1.2371	1.2386	1.2386	1.2386	1.2386	1.2386	1.2386	1.2386	1.2386	1.2386	1.2386	1.2386	1.2386	1.2386	1.2386	1.2386	
SUN VEL,M/SEC	1000.8	947.7	1000.6	1000.0	990.1	974.0	959.4	944.0	928.0	911.0	894.0	876.0	858.0	840.0	822.0	804.0	786.0	768.0	750.0	732.0	
MACH NUMBER	0.0	1.000	0.059	0.119	0.437	0.699	0.974	1.238	1.482	1.684	1.846	1.974	2.069	2.128	2.168	2.198	2.218	2.230	2.235	2.240	
AE/AT	1.0000	1.0000	10.000	5.000	1.5000	1.1000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	
CSTAR, FT/SEC	4502	4502	4502	4502	4502	4502	4502	4502	4502	4502	4502	4502	4502	4502	4502	4502	4502	4502	4502	4502	
CF	0.691	0.691	0.043	0.087	0.315	0.496	0.696	0.882	1.033	1.165	1.278	1.368	1.438	1.488	1.520	1.538	1.550	1.558	1.562	1.567	
IVAC LB-SEC/LB	174.5	174.5	1403.4	705.8	230.9	184.1	148.1	128.5	107.5	92.5	80.5	70.5	62.5	56.5	51.5	47.5	44.5	42.5	41.5	39.5	
ISP, LB-SEC/LB	96.6	96.6	6.0	12.1	44.1	69.4	92.4	112.4	128.4	141.4	151.4	158.4	163.4	167.4	170.4	172.4	173.4	174.4	174.4	174.4	

TABLE 27. THEORETICAL ROCKET PERFORMANCE ASSUMING EQUILIBRIUM COMPOSITION DURING EXPANSION (page 2 of 2)
[30,000 psi]

[illegible]

NOTE. WEIGHT FRACTION OF FUEL IN TOTAL FUELS AND OF OXIDANT IN TOTAL OXIDANTS

TABLE 28. THEORETICAL ROCKET PERFORMANCE ASSUMING EQUILIBRIUM COMPOSITION DURING EXPANSION (page 1 of 2)
[40,000 psi]

PC = 40000.0 PSIA										WT FRACTION (SEE NOTE)				ENERGY CAL/MOL		STATE		TEMP DEG K		DENSITY G/CC	
CHEMICAL FORMULA										O 10.27200				N 2.63580		H 7.36400		C 6.00000			
FUEL	C	6.00000	H	7.36400	N	2.63580	O	10.27200													
FUEL	C	1.00000																			
FUEL	C	12.00000	H	11.00000	N	1.00000															
FUEL	C	18.00000	H	14.00000	O	4.00000															
FUEL	NA	2.00000	S	1.00000	O	4.00000															
FUEL	CA	1.00000	C	1.00000	O	3.00000															
O/F= 0.0										PERCENT FUEL= 100.0000				EQUIVALENCE RATIO= 1.6846				PHI= 0.0		REACTANT DENSITY= 0.0	
CHAMBER										EXIT		EXIT		EXIT		EXIT		EXIT		EXIT	
PC/P										THROAT		EXIT		EXIT		EXIT		EXIT		EXIT	
P, ATM	1.0000	1.7962	1.0021	1.0087	1.1238	1.3418	32.975	81.833	191.46	570.27											
T, DEG K	2721.83	1515.28	2716.10	2698.32	2421.95	2028.44	82.542	33.261	14.216	4.7729											
RHO, G/CC	2379.2	2125.6	2378.2	2375.2	2326.6	2248.7	1272.8	1137.8	1058.2	974.2											
H, CAL/G	3.4035-1	2.1208-1	3.3977-1	3.3797-1	3.0969-1	2.6835-1	1.9764-2	9.1215-3	4.3038-3	1.6220-3											
S, CAL/(G)(K)	-594.6	-701.9	-595.0	-596.3	-616.5	-650.0	-1088.8	-1174.6	-1245.9	-1328.3											
M, MOL WT	24.412	24.412	24.412	24.412	24.411	24.411	25.007	25.605	26.288	27.166											
(DLV/DLP)T	-1.00192	-1.00203	-1.00192	-1.00191	-1.00190	-1.00191	-1.03312	-1.05198	-1.09869	-1.09830											
(DLV/DLP)P	1.0090	1.0118	1.0090	1.0090	1.0093	1.0100	1.4067	1.7192	2.6609	2.5930											
CP, CAL/(G)(K)	0.4300	0.4258	0.4300	0.4299	0.4287	0.4271	0.8152	1.1948	2.5744	2.5722											
GAMMA (S)	1.2358	1.2402	1.2358	1.2359	1.2369	1.2384	1.1901	1.1628	1.1226	1.1147											
SON VEL, M/SEC	1000.7	947.6	1000.5	999.9	990.0	973.9	709.7	655.5	613.0	576.5											
MACH NUMBER	0.0	1.000	0.059	0.119	0.437	0.699	2.866	3.361	3.809	4.298											
AE/AT	1.0000	1.0000	10.000	5.0000	1.5000	1.1000	5.0000	10.000	20.000	50.000											
CSTAR, FT/SEC	4502	4502	4502	4502	4502	4502	4502	4502	4502	4502											
CF	0.690	0.690	0.043	0.087	0.315	0.496	1.482	1.605	1.701	1.806											
IVAC LB-SEC/LB	174.5	174.5	1401.4	705.8	230.9	184.1	228.6	241.8	252.7	264.9											
Isp, LB-SEC/LB	96.6	96.6	6.0	12.1	44.1	69.4	207.4	224.7	238.1	252.7											

TABLE 28. THEORETICAL ROCKET PERFORMANCE ASSUMING EQUILIBRIUM COMPOSITION DURING EXPANSION (page 2 of 2)
[40,000 psi]

HOLE FRACTIONS

	C1S1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0</
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ADDITIONAL PRODUCTS WHICH WERE CONSIDERED BUT WHOSE MOLE FRACTIONS WERE LESS THAN 0.5000E-05 FOR ALL ASSIGNED CONDITIONS

C	CH	CH2	CH3	CN	CNV	CN2	C5	C52	C2
C2H	C2H2	C2H4	C2H6	C2N	C2N2	C2O	C3	C302	C4
C(S)	CA(S)	CA(S)	CA(L)	CA	CACO3(S)	CAO(L)	CAO	CAOH	CAO2H2(S)
CASO4(S)	CA2	HNO	HNO	HNO2	HNO3	H02	H2O(S)	H2O(L)	H2O2
H2SO4	N	NCO	NCO	NH	NH2	NO	NO2	NO3	N2H4
N2O4	N2O5	N3	N3	NA(S)	NA(L)	NACN(S)	NACN(L)	NAO	NAOH(S)
NAO2(S)	NA2	NA2CO3(S)	NA2C2N2	NA2C2N2	NA2O(S)	NA2O(S)	NA2O(L)	NA2O	NA2O2(S)
NA2O2H2	NA2SO4(S)	NA2SO4(S)	NA2SO4(S)	NA2SO4(S)	NA2SO4(L)	NA2SO4	O	O2	O3
S(S)	S	S(L)	SN	SO	SO2	SO3	S2	S2O	S8

NOTE. WEIGHT FRACTION OF FUEL IN TOTAL FUELS AND OF OXIDANT IN TOTAL OXIDANTS

TABLE 29. THEORETICAL ROCKET PERFORMANCE ASSUMING EQUILIBRIUM COMPOSITION DURING EXPANSION (page 1 of 2)
[50,000 psi]

PC = 50000.0 PSIA

CHEMICAL FORMULA										WT FRACTION (SEE NOTE)				ENERGY CAL/MOL		STATE		TEMP DEG K		DENSITY G/CC	
FUEL	C	6.00000	H	7.36400	N	2.63580	O	10.27200		0.951500				-164700.000		S		298.15		0.0	
FUEL	C	1.00000								0.004000				0.0		S		298.15		0.0	
FUEL	C	12.00000	H	11.00000	N	1.00000				0.007500				27900.000		S		298.15		0.0	
FUEL	C	18.00000	H	14.00000	O	4.00000				0.030000				-200000.000		S		298.15		0.0	
FUEL	NA	2.00000	S	1.00000	O	4.00000				0.005000				-326300.000		S		298.15		0.0	
FUEL	CA	1.00000	C	1.00000	O	3.00000				0.002000				-287900.000		S		298.15		0.0	
Q/F = 0.0 PERCENT FUEL = 100.0000 EQUIVALENCE RATIO = 1.6846 PHI = 0.0										REACTANT DENSITY = 0.0											
CHAMBER										EXIT		EXIT		EXIT		EXIT		EXIT		EXIT	
PC/P	1.0000	1.7960	1.0021	1.0087	1.1238	1.3418	32.810	81.400	190.45	568.06											
P, ATM	3402.28	1894.40	1395.17	1172.92	3027.59	2535.70	103.70	41.797	17.865	5.9893											
T, DEG K	2380.2	2127.0	2379.3	2376.3	2327.7	2249.9	1284.6	1149.7	1069.7	983.7											
RHO, G/CC	4.2545-1	2.6511-1	4.2474-1	4.2249-1	3.8713-1	3.3545-1	2.4702-2	1.1396-2	5.3754-3	2.0252-3											
H, CAL/G	-594.6	-701.8	-595.0	-596.3	-616.9	-649.9	-1088.9	-1175.1	-1246.9	-1329.9											
S, CAL/(G)(K)	2.0282	2.0282	2.0282	2.0282	2.0282	2.0282	2.0282	2.0282	2.0282	2.0282											
M, MOL WT	24.424	24.425	24.424	24.424	24.423	24.423	25.108	25.722	26.411	27.294											
(DLV/DLPIT)	-1.00260	-1.00285	-1.00261	-1.00260	-1.00260	-1.00264	-1.03690	-1.05417	-1.09833	-1.08789											
(DLV/DLTIP)	1.0124	1.0170	1.0124	1.0124	1.0129	1.0141	1.4498	1.7432	2.6354	2.5680											
CP, CAL/(G)(K)	0.4316	0.4286	0.4316	0.4315	0.4305	0.4292	0.8520	1.2097	2.5065	2.5052											
GAMMA (S)	1.2355	1.2399	1.2355	1.2356	1.2366	1.2381	1.1881	1.1627	1.1238	1.1158											
SON VEL./M/SEC	1000.5	947.5	1000.3	999.7	989.9	973.8	710.9	657.3	615.2	578.2											
MACH NUMBER	0.0	1.000	0.059	0.119	0.437	0.699	2.861	3.353	3.798	4.290											
AE/AT	1.0000	1.0000	10.000	5.0000	1.5000	1.1000	5.0000	10.000	20.000	50.000											
CS*AR, FT/SEC	4503	4503	4503	4503	4503	4503	4503	4503	4503	4503											
CF	0.690	0.690	0.043	0.087	0.315	0.496	1.482	1.606	1.702	1.807											
IVAC LB-SEC/LB	174.5	174.5	1402.3	705.9	230.9	184.1	228.7	242.0	252.9	265.3											
ISP, LB-SEC/LB	96.6	96.6	6.0	12.1	44.1	69.4	207.4	224.8	238.3	252.9											

TABLE 31. THEORETICAL ROCKET PERFORMANCE ASSUMING FROZEN COMPOSITION DURING EXPANSION (page 1 of 2)
[10,000 psi]

[illegible]

TABLE 31. THEORETICAL ROCKET PERFORMANCE ASSUMING FROZEN COMPOSITION DURING EXPANSION (page 2 of 2)
[10,000 psi]

MOLE FRACTIONS

CH2O	0.000003	CH4	0.000001	CO	0.45184	COS	0.000009
CN2	0.10986	CAO(S)	0.00026	CAO2H2	0.00023	H	0.00020
HCN	0.000005	HCO	0.00001	HNCO	0.00001	H2	0.13588
H2O	0.18956	H2S	0.00072	NH3	0.00014	N2	0.10930
NA	0.00038	NACN	0.00001	NAH	0.00003	NAOH	0.00129
OH	0.00005	SH	0.00001	SO	0.00001	SO2	0.00001

ADDITIONAL PRODUCTS WHICH WERE CONSIDERED PUT WHOSE MOLE FRACTIONS WERE LESS THAN 0.50000E-05 FOR ALL ASSIGNED CONDITIONS

C(S)	C	CH	CH3	CN	CN2	CS	CS2
C2	C2H	C2H2	C2H6	C2N	C2N2	C3	C3O2
C4	C5	CA(S)	CA(L)	CA	CACO3(S)	CAO(L)	CAO
CAOH	CAO2H2(S)	CAS(S)	CA2	HNO	HNO3	HNO2	H2O(S)
H2O(L)	H2O2	H2SO4(L)	N	NCO	NH2	NO	NO2
NO3	N2H4	N2O	N2O5	N3	NA(L)	NACN(S)	NACN(L)
NAO	NAOH(S)	NAOH(L)	NA2	NA2CO3(S)	NA2CO3(L)	NA2C2N2	NA2O(S)
NA2O(S)	NA2O(L)	NA2O	NA2O2(S)	NA2CO3(S)	NA2SO4(S)	NA2SO4(S)	NA2SO4(L)
NA2SO4	O	O2	NA2O2(S)	NA2O2H2	NA2SO4(S)	SO3	S2
S2O	SR		S(S)	S(L)	SN		

NOTE. WEIGHT FRACTION OF FUEL IN TOTAL FUELS AND OF OXIDANT IN TOTAL OXIDANTS

TABLE 32. THEORETICAL ROCKET PERFORMANCE ASSUMING FROZEN COMPOSITION DURING EXPANSION (page 1 of 2)
[20,000 psi]

PC = 20000.0 PSIA										
CHEMICAL FORMULA										
FUEL	C	6.00000	H	7.36400	N	2.63580	O	10.27200		
FUEL	C	1.00000								
FUEL	C	12.00000	H	11.00000	N	1.00000				
FUEL	C	18.00000	H	14.00000	O	4.00000				
FUEL	NA	2.00000	S	1.00000	O	4.00000				
FUEL	CA	1.00000	C	1.00000	O	3.00000				
C/F= 0.0 PERCENT FUEL= 100.0000 EQUIVALENCE RATIO= 1.6846 PHI= 0.0 REACTANT DENSITY= 0.0										
WT FRACTION (SEE NOTE) ENERGY CAL/MOL STATE TEMP DEG K DENSITY G/CC										
		0.951500				-164700.000	S		298.15	0.0
		0.004000				0.0	S		298.15	0.0
		0.007500				27900.000	S		298.15	0.0
		0.030000				-200000.000	S		298.15	0.0
		0.005000				-326900.000	S		298.15	0.0
		0.002000				-287900.000	S		298.15	0.0
CHAMBER THROAT										
PC/P		1.0000	1.8010	1.0021	1.0088	1.1244	1.3436	36.097	97.680	937.13
P, ATM		1360.91	755.65	1358.01	1349.07	1210.37	1012.92	37.701	13.932	1.4522
T, DEG K		2377.3	2117.0	2376.3	2373.2	2323.3	2243.3	1131.5	903.2	520.6
RHO, G/CC		1.7016-1	1.0610-1	1.6987-1	1.6897-1	1.5485-1	1.3421-1	9.9040-3	4.5851-3	8.2921-4
M, CAL/G		-594.6	-702.2	-595.0	-596.3	-617.0	-650.2	-1088.6	-1170.8	-1299.3
S, CAL/(G)(K)		2.1028	2.1028	2.1028	2.1028	2.1028	2.1028	2.1028	2.1028	2.1028
M, MOL WT		24.390	24.390	24.390	24.390	24.390	24.390	24.390	24.390	24.390
CP, CAL/(G)(K)		0.4163	0.4102	0.4163	0.4162	0.4152	0.4133	0.3680	0.3519	0.3195
GAMMA (S)		1.2433	1.2479	1.2433	1.2434	1.2442	1.2455	1.2844	1.3013	1.3423
SON VEL, M/SEC		1003.8	949.0	1003.6	1002.9	992.6	975.9	703.8	633.0	567.7
MACH NUMBER		0.0	1.000	0.059	0.119	0.437	0.699	2.889	3.469	4.976
AE/AT										
CSTAR, FT/SEC		1.0000	1.0000	10.000	5.0000	1.5000	1.1000	5.0000	10.000	50.000
CF		4493	4493	4493	4493	4493	4493	4493	4493	4493
IVAC LB-SEC/LB		0.693	0.693	0.043	0.087	0.316	0.498	1.485	1.603	1.773
ISP, LB-SEC/LB		174.3	1399.6	704.3	230.5	183.9	226.7	238.2	246.8	255.1
		96.8	6.0	12.2	44.2	69.5	207.3	223.9	236.1	247.6

TABLE 32. THEORETICAL ROCKET PERFORMANCE ASSUMING FROZEN COMPOSITION DURING EXPANSION (page 2 of 2)
[20,000 psi]

MOLE FRACTIONS

CH2O	0.00005	CH4	0.00006	CO	0.45178	COS	0.00009
CO2	0.11001	CAO(S)	0.00026	CAO2H2	0.00023	H	0.00014
HCN	0.00009	HCO	0.00001	H2CO	0.00002	H2	0.13562
H2O	0.18959	H2S	0.00071	NH3	0.00027	N2	0.10924
NA	0.00028	NACN	0.00003	NAH	0.00003	NADH	0.00137
OH	0.00004	SH	0.00002				

ADDITIONAL PRODUCTS WHICH WERE CONSIDERED BUT WHOSE MOLE FRACTIONS WERE LESS THAN 0.50000E-05 FOR ALL ASSIGNED CONDITIONS

C(S)	C	CH	CH2	CH3	CN	CN2	CS
C2	C2H	C2H2	C2H4	C2H6	C2N	C2O	C3
C4	C5	CA(S)	CA(S)	CA(L)	CA	CAO3(S)	CAO
CAOH	CAO2H2(S)	CAS(S)	CASO4(S)	CA2	HNO	HNO3	H2O(S)
H2O(L)	H2O2	H2SO4(L)	H2SO4	N	NCO	NH2	NO2
NO3	N2H4	N2O	N2O4	N2O5	N3	NA(L)	NACN(S)
NAO	NAOH(S)	NAOH(L)	NAO2(S)	NA2	NA2CO3(S)	NA2CO3(L)	NA2O(L)
NA2O(S)	NA2O(L)	NA2O	NA2O2(S)	NA2O2(S)	NA2O2H2	NA2O2N2	NA2O(S)
NA2SO4	O	O2	O3	S(S)	S(L)	NA2SO4(S)	NA2SO4(L)
SO3	S2	S2O	S8		S	SN	SO2

NOTE. WEIGHT FRACTION OF FUEL IN TOTAL FUELS AND OF OXIDANT IN TOTAL OXIDANTS

TABLE 33. THEORETICAL ROCKET PERFORMANCE ASSUMING FROZEN COMPOSITION DURING EXPANSION (page 1 of 2)
[30,000 psi]

PC = 30000.0 PSIA

CHEMICAL FORMULA									
FUEL	C	6.00000	H	7.36400	N	2.63580	O	10.27200	
FUEL	C	1.00000							
FUEL	C	12.00000	H	11.00000	N	1.00000			
FUEL	C	18.00000	H	14.00000	O	4.00000			
FUEL	NA	2.00000	S	1.00000	O	4.00000			
FUEL	CA	1.00000	C	1.00000	O	3.00000			
O/F= 0.0 PERCENT FUEL= 100.0000 EQUIVALENCE RATIO= 1.6846 PHI= 0.0									
		WT FRACTION (SEE NOTE)	ENERGY CAL/MOL	STATE	TEMP DEG K	DENSITY G/CC			
		0.951500	-164700.000	S	298.15	0.0			
		0.004000	0.0	S	298.15	0.0			
		0.007500	27900.000	S	298.15	0.0			
		0.030000	-200000.000	S	298.15	0.0			
		0.005000	-326300.000	S	298.15	0.0			
		0.002000	-287900.000	S	298.15	0.0			
							REACTANT DENSITY=	0.0	

PC/P	CHAMBER	THROAT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT
P, ATM	1.0000	1.8009	1.0021	1.0088	1.1244	1.3435	1.6083	1.97626	2.59.47	3.936.29	4.936.29
T, DEG K	2041.37	1133.54	2037.01	2023.61	1815.57	1519.43	56.575	20.910	7.8675	2.1803	2.1803
RHO, G/CC	2378.2	2117.9	2377.2	2374.1	2324.2	2244.3	1132.5	904.2	717.4	521.3	521.3
M, CAL/G	2.5525-1	1.5915-1	2.5481-1	2.5346-1	2.3229-1	2.0132-1	1.4855-2	6.8770-3	3.2613-3	1.2436-3	1.2436-3
S, CAL/(G)(K)	-594.6	-702.2	-595.0	-596.3	-617.0	-650.1	-1088.6	-1170.9	-1235.2	-1299.5	-1299.5
M, MUL WT	2.0698	2.0698	2.0698	2.0698	2.0698	2.0698	2.0698	2.0698	2.0698	2.0698	2.0698
CP, CAL/(G)(K)	24.401	24.401	24.401	24.401	24.401	24.401	24.401	24.401	24.401	24.401	24.401
GAMMA (S)	0.4164	0.4102	0.4164	0.4163	0.4152	0.4134	0.3681	0.3519	0.3363	0.3195	0.3195
SON VEL, M/SEC	1.2431	1.2477	1.2432	1.2432	1.2440	1.2453	1.2841	1.3011	1.3195	1.3421	1.3421
MACH NUMBER	1003.7	948.9	1003.5	1002.9	992.6	975.9	703.9	633.1	567.9	488.3	488.3
	0.0	1.000	0.059	0.119	0.437	0.699	2.888	3.469	4.077	4.974	4.974
AE/AT	1.0000	1.0000	10.000	5.0000	1.5000	1.1000	5.0000	10.000	20.000	50.000	50.000
CSTAR, FT/SEC	44.93	44.93	44.93	44.93	44.93	44.93	44.93	44.93	44.93	44.93	44.93
CF	0.693	0.693	0.043	0.087	0.316	0.498	1.485	1.603	1.690	1.773	1.773
IVAC LB-SEC/LB	174.3	1400.6	704.3	230.5	183.9	226.7	238.2	238.2	246.9	255.1	255.1
ISP, LB-SEC/LB	96.8	6.0	12.2	44.2	69.5	207.3	223.9	223.9	236.1	247.7	247.7

TABLE 33. THEORETICAL ROCKET PERFORMANCE ASSUMING FROZEN COMPOSITION DURING EXPANSION (page 2 of 2)
[30,000 psi]

MOLE FRACTIONS

CH ₂ O	0.00007	CH ₄	0.00013	CO	0.45165	COS	0.00010
CO ₂	0.11021	CAO(S)	0.00026	CAO ₂ H ₂	0.00023	H	0.00012
HCN	0.00014	HCO	0.00002	HNCO	0.00003	H ₂	0.13531
H ₂ O	0.18964	H ₂ S	0.00074	NH ₃	0.00040	N ₂	0.10919
NA	0.00023	NACN	0.00005	NAH	0.00003	NAOH	0.00140
OH	0.00003	SH	0.00002				

ADDITIONAL PRODUCTS WHICH WERE CONSIDERED BUT WHOSE MOLE FRACTIONS WERE LESS THAN 0.50000E-05 FOR ALL ASSIGNED CONDITIONS

C(S)	C	CH	CH ₃	CN	CNN	CN ₂	CS
C ₂	C ₂ H	C ₂ H ₂	C ₂ H ₆	C ₂ N	C ₂ N ₂	C ₂ O	C ₃
C ₄	C ₅	CA(S)	CA(L)	CA	CACO ₃ (S)	CACO ₃ (S)	CAO
CAOH	CAO ₂ H ₂ (S)	CAS(S)	CA ₂	HNO	HNO ₂	HNO ₃	H ₂ O(S)
H ₂ O(L)	H ₂ O	H ₂ SO ₄ (L)	N	NC	NH	NH ₂	NO ₂
NO ₃	N ₂ H ₄	N ₂ O	N ₂ O ₅	N ₃	NA(S)	NA(L)	NACN(L)
NAO	NAOH(S)	NAOH(L)	NA ₂	NA ₂ CO ₃ (S)	NA ₂ CO ₃ (S)	NA ₂ CO ₃ (L)	NA ₂ O(S)
NA ₂ O(S)	NA ₂ O(L)	NA ₂ O	NA ₂ O ₂ (S)	NA ₂ O ₂ H ₂	NA ₂ SO ₄ (S)	NA ₂ SO ₄ (S)	NA ₂ SO ₄ (L)
NA ₂ SO ₄	O	O ₂	S(S)	S(L)	S	SN	SO
SO ₃	S ₂	S ₂ O					SO ₂

NOTE. WEIGHT FRACTION OF FUEL IN TOTAL FUELS AND OF OXIDANT IN TOTAL OXIDANTS

TABLE 34. THEORETICAL ROCKET PERFORMANCE ASSUMING FROZEN COMPOSITION DURING EXPANSION (page 1 of 2)
[40,000 psi]

PC = 40000.0 PSIA									
CHEMICAL FORMULA				PERCENT FUEL= 100.0000			EQUIVALENCE RATIO= 1.6846		
FUEL	C	H	N	O	WT FRACTION (SEE NOTE)	ENERGY CAL/MOL	STATE	TEMP DEG K	DENSITY G/CC
FUEL	6.00000				0.951500	-164700.000	S	298.15	0.0
FUEL	1.00000				0.004000	0.0	S	298.15	0.0
FUEL	12.00000				0.007500	27900.000	S	298.15	0.0
FUEL	18.00000				0.030000	-200000.000	S	298.15	0.0
FUEL	2.00000				0.005000	-326300.000	S	298.15	0.0
FUEL	1.00000				0.002000	-287900.000	S	298.15	0.0
Q/F= 0.0 PH1= 0.0 REACTANT DENSITY= 0.0									
CHAMBER THRUST									
PC/P	CHAMBER	THRUST	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT
P, ATM	1.0000	1.8008	1.0021	1.0088	1.1243	1.3435	36.066	97.566	935.37
T, DEG K	2721.83	1511.48	2716.03	2698.15	2420.81	2025.96	75.468	27.897	2.9099
RHO, G/CC	3.4035-1	2.1221-1	3.3977-1	3.3797-1	3.0973-1	2.6844-1	1.133.6	905.2	522.1
H, CAL/G	-594.6	-702.2	-595.0	-596.3	-617.0	-650.1	-1088.6	-1171.0	-1299.6
S, CAL/(G)(K)	2.0463	2.0463	2.0463	2.0463	2.0463	2.0463	2.0463	2.0463	2.0463
M, MOL WT	24.412	24.412	24.412	24.412	24.412	24.412	24.412	24.412	24.412
CP, CAL/(G)(K)	0.4164	0.4103	0.4164	0.4163	0.4153	0.4134	0.3681	0.3520	0.3195
GAMMA (SI)	1.2430	1.2475	1.2430	1.2430	1.2438	1.2452	1.2839	1.3008	1.3419
SUN VEL, M/SEC	1003.6	948.9	1003.4	1002.8	992.5	975.8	704.1	633.3	488.5
MACH NUMBER	0.0	1.000	0.059	0.119	0.437	0.699	2.888	3.468	4.972
AE/AT	1.0000	1.0000	10.000	5.0000	1.5000	1.1000	5.0000	10.000	50.000
CF	4494	4494	4494	4494	4494	4494	4494	4494	4494
IVAC LB-SEC/LB	0.693	0.043	0.087	0.316	0.498	1.485	1.603	1.773	2.55.2
ISP, LB-SEC/LB	174.3	1400.3	704.3	230.5	183.9	226.7	238.3	247.7	247.7

TABLE 34. THEORETICAL ROCKET PERFORMANCE ASSUMING FROZEN COMPOSITION DURING EXPANSION (page 2 of 2)
[40,000 psi]

MOLE FRACTIONS

CH ₂ O	0.00010	CH ₄	0.00023	CO	0.45147	COS	0.00010
CO ₂	0.11044	CAO(S)	0.00026	CAO ₂ H ₂	0.00023	H	0.00010
HCN	0.00018	HCO	0.00002	HNCO	0.00004	H ₂	0.13495
H ₂ O	0.18969	H ₂ S	0.00074	NH ₃	0.00054	N ₂	0.10914
NA	0.00021	NACN	0.00006	NAH	0.00004	NADH	0.00141
OH	0.00003	SH	0.00002				

ADDITIONAL PRODUCTS WHICH WERE CONSIDERED BUT WHOSE MOLE FRACTIONS WERE LESS THAN 0.50000E-05 FOR ALL ASSIGNED CONDITIONS

C(S)	C	CH	CH ₂	CH ₃	CN	CNN	CN ₂	CS	CS ₂
C ₂	C ₂ H	C ₂ H ₂	C ₂ H ₄	C ₂ H ₆	C ₂ N	C ₂ N ₂	C ₂ O	C ₃	C ₃ O ₂
C ₄	C ₅	CA(S)	CA(S)	CA(L)	CA	CAO ₃ (S)	CAO ₃ (S)	CAO(L)	CAO
CAOH	CAO ₂ H ₂ (S)	CAS(S)	CASO ₄ (S)	CA ₂	HNO	HNO ₂	HNO ₃	H ₂ O(S)	H ₂ O(S)
H ₂ O(L)	H ₂ O ₂	H ₂ SO ₄ (L)	H ₂ SO ₄	N	NCO	NH	NH ₂	NO	NO ₂
NO ₃	N ₂ H ₄	N ₂ O	N ₂ O ₄	N ₂ O ₅	N ₃	NA(S)	NA(L)	NACN(S)	NACN(L)
NAO	NAOH(S)	NAOH(L)	NAO ₂ (S)	NA ₂	NA ₂ CO ₃ (S)	NA ₂ CO ₃ (S)	NA ₂ CO ₃ (L)	NA ₂ C ₂ N ₂	NA ₂ O(S)
NA ₂ O(S)	NA ₂ O(L)	NA ₂ O	NA ₂ O ₂ (S)	NA ₂ O ₂ (S)	NA ₂ O ₂ H ₂	NA ₂ SO ₄ (S)	NA ₂ SO ₄ (S)	NA ₂ SO ₄ (S)	NA ₂ SO ₄ (L)
NA ₂ SO ₄	O	O ₂	O ₃	S(S)	SLI	S	SN	SO	SO ₂
SO ₃	S ₂	S ₂ O	S ₈						

NOTE. WEIGHT FRACTION OF FUEL IN TOTAL FUELS AND OF OXIDANT IN TOTAL OXIDANTS

TABLE 35. THEORETICAL ROCKET PERFORMANCE ASSUMING FROZEN COMPOSITION DURING EXPANSION (page 2 of 2)
[50,000 psi]

MOLE FRACTIONS

CH2O	0.00012	CH3	0.00001	CH4	0.00035	CO	0.45127
COS	0.00010	CO2	0.11071	CAO(S)	0.00025	CAO2H2	0.00023
H	0.00009	HCN	0.00022	HCO	0.00002	HNCO	0.00004
H2	0.13455	H2O	0.18976	H2S	0.00074	NH3	0.00067
N2	0.10909	NA	0.00018	NACN	0.00008	NAH	0.00004
NAOH	0.00142	OH	0.00002	SH	0.00002		

ADDITIONAL PRODUCTS WHICH WERE CONSIDERED BUT WHOSE MOLE FRACTIONS WERE LESS THAN 0.50000E-05 FOR ALL ASSIGNED CONDITIONS

C(S)	C	CH	CH2	CN	CN2	CS	C2
C2H	C2H2	C2H4	C2H6	C2N	C2N2	C3	C4
C5	CA(S)	CA(S)	CA(L)	CA	CAC03(S)	CAO	CAOH
CAO2H2(S)	CAS(S)	CAS04(S)	CA2	HNO	HNO3	H2O(S)	H2O(L)
H2O2	H2SO4(L)	H2SO4	N	NCO	NH2	N02	N03
N2H4	N2O	N2O4	N2O5	N3	NA(L)	NACN(L)	NAO
NAOH(S)	NAOH(L)	NAO2(S)	NA2	NA2CO3(S)	NA2C03(L)	NA2C2N2	NA2O(S)
NA2O(L)	NA2O	NA2O2(S)	NA2O2(S)	NA2CO4(S)	NA2SO4(S)	NA2SO4(L)	NA2SO4
O	O2	O3	S(S)	S	SN	SO	S03
S2	S2O	S8				S02	

NOTE. WEIGHT FRACTION OF FUEL IN TOTAL FUELS AND OF OXIDANT IN TOTAL OXIDANTS

TABLE 36. THEORETICAL ROCKET PERFORMANCE ASSUMING FROZEN COMPOSITION DURING EXPANSION (page 2 of 2)
[60,000 psi]

MOLE FRACTIONS

CH ₂ O	0.00015	CH ₃	0.000001	CH ₄	0.00050	CO	0.45103
CNS	0.00010	CO ₂	0.11100	CAO(S)	0.00025	CAO ₂ H ₂	0.00023
H	0.00008	HCN	0.00027	HCO	0.00003	HNC	0.00005
H ₂	0.13410	H ₂ O	0.18984	H ₂ S	0.00075	NH ₂	0.00001
NH ₃	0.00079	N ₂	0.10905	NA	0.00017	NACN	0.00009
NAH	0.00004	NAOH	0.00142	OH	0.00002	SH	0.00001

ADDITIONAL PRODUCTS WHICH WERE CONSIDERED BUT WHOSE MOLE FRACTIONS WERE LESS THAN 0.50000E-05 FOR ALL ASSIGNED CONDITIONS

C(S)	C	CH	CH ₂	CN	CN ₂	CN ₂	CS	C ₂
C ₂ H	C ₂ H ₂	C ₂ H ₄	C ₂ H ₆	C ₂ N	C ₂ N ₂	C ₂ O	C ₃	C ₄
C ₅	CA(S)	CA(S)	CA(L)	CA	CAC ₂ O ₃ (S)	CAC ₂ O ₃ (S)	CAO(L)	CAOH
CAO ₂ H ₂ (S)	CAS(S)	CAS ₂ O ₄ (S)	CA ₂	HNO	HNO ₂	HNO ₃	H ₂ O	H ₂ O(L)
H ₂ O ₂	H ₂ SO ₄ (L)	H ₂ SO ₄	N	NCO	NH	NO	NO ₂	N ₂ H ₄
N ₂ O	N ₂ O ₄	N ₂ O ₅	N ₃	NA(S)	NA(L)	NACN(S)	NACN(L)	NAOH(S)
NAOH(L)	NAO ₂ (S)	NA ₂ O	NA ₂ CO ₃ (S)	NA ₂ CO ₃ (S)	NA ₂ CO ₃ (L)	NA ₂ C ₂ N ₂	NA ₂ O(S)	NA ₂ O(L)
NA ₂ O	NA ₂ O ₂ (S)	NA ₂ O ₂ (S)	NA ₂ O ₂ H ₂	NA ₂ SO ₄ (S)	NA ₂ SO ₄ (S)	NA ₂ SO ₄ (S)	NA ₂ SO ₄ (L)	O
O ₂	O ₃	Si(S)	Si(L)	S	SN	SO	SO ₂	S ₂
S ₂ O	S ₈						SO ₃	

NOTE. WEIGHT FRACTION OF FUEL IN TOTAL FUELS AND OF OXIDANT IN TOTAL OXIDANTS

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